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POSSIBLE INFLUENCE OF GLOBAL WARMING ON CLIMATE VARIABILITY IN THE CENTRAL UNITED STATES

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Introduction

The primary manifestation of climate change may be variability, or the effects of variability, as opposed to climatic shift. During the 1960s, there was a good deal of concern within the academic community and, to some extent, expressed by the public regarding the global cooling trend that had become apparent in several parts of the world. From about 1910 to 1940, the earth experienced a warming trend, followed by an abrupt decrease in global temperature that continued until about 1972. Observations of glacial activity in the Austrian Alps and on Mount McKinley in Alaska revealed a marked glacial retreat up to 1940 and glacial expansion between 1940 and 1972 (Matthews, 1976). The period of apparent global cooling was also a period of diminished inter-annual variability when over-winter heating requirements, summer heat stress, and midwest crop yields were predictable within reasonable limits of uncertainty.

Accumulated climate observations, together with theoretical understanding of global climate processes, may provide a framework for risk analysis of climatic episodes. To some extent, risk can be economically managed, whereas uncertainty cannot be directly quantified. Analysis of historical patterns and climate cycles enables the use of risk management methodology in production and marketing decisions.

United States Grain Yields

The historical grain yield in the central United States reflects technology, economy, and weather. Federal and state policy may influence the total production but has little effect on yield per harvested unit of land. When yield records are expected over a period of several years, the influence of the technology trend is apparent. Weather is a less certain and highly variable factor. Figure 1 shows the average yield for corn in Iowa from 1900 through 1990. The average yield for a unit of land increased slowly during the first half of the century. Rapid improvement in yield is apparent from the 1950s through the early 1970s. It is likely that improved management of crop pests (weed, disease, and insect pests) together with modern management of soil fertility and improved cultivars resulted in substantial crop yield gains.

Year-to-year consistency of grain yield was noted during the yield revolution of the 1960s. Improved management and the introduction of environmentally tolerant cultivars may have contributed to both the rising yield trend and the diminished year-to-year variability of yield. The primary factor influencing the consistency of the yield trend was consistently favorable weather. A dramatic reversion to variability of yield became apparent in the early 1970s. It is generally assumed that the long-term trend of yield is related to technology, and the year-to-year variability is most directly attributable to climatic conditions. Some of the variability is a result of pest activity;

however, pest movement, pest development, and damage to crops are somewhat weather dependent.

The weather parameters most often associated with reduced crop yield are temperature and precipitation. Excessively elevated temperature and reduced precipitation are commonly considered responsible for reduced crop yields. It is assumed that warm temperatures increase the demands of the atmosphere on crops to expend water. When plants do not have sufficient water available to meet the atmospheric demand, they may wilt or in some other way restrict water loss. When water loss is restricted, the uptake of carbon dioxide is also restricted and growth is limited. It is normally assumed that crop yield is directly influenced by the proportion of the atmospheric demand that is realized.

Year-to-year variability of crop yield was greater for Iowa during the 1900-1955 period than during the subsequent 17 years. Variability returned during the mid-1970s. A similar pattern exists for all Corn Belt states. One indicator of the influence of temperature on yield is the stress degree unit.

Stress Degree Units

Temperature in excess of 86°F begins to exceed the optimum for plant growth. This is especially true if the plant water supply is less than ideal. The stress degree unit is a method of quantifying the influence of stressful temperatures on crops. The stress unit is computed when the daily maximum tempera-ture exceeds 86°F (30°C). If the minimum temperature also exceeds 86°F, the maximum and minimum temperatures are averaged and 86 is subtracted from the result to yield the daily heat stress contribution. When the minimum temperature is below 86°F, the unit is computed as the maximum temperature plus 86 divided by 2 less 86.

The period of global cooling, 1940-1972, was characterized by a decreasing severity of stressful conditions during the midwest growing season (Figure 2). The return to warming since 1972 appears to have influenced an increase in the severity of stressful conditions influencing crop production.

Several assessments of crop response to doubled carbon dioxide have been computed using "plant process" based modeling (Adams et al., 1990). To date, simulations have considered only a step-wise shift in average conditions, which assume that the distribution of extreme events would be similar to those presently observed. Should global warming result in greater variability of factors influencing production, the modeled response of the production system may fall short of reality. It is thought that the basic process models are capable of representing the response of crops to changed conditions if the routine used to generate hypothetical weather data is adjusted to allow realistically increased variability of the environment.

Plant process models may be used to evaluate variability as well as changes of average conditions. Two factors must be evaluated before such analyses are meaningful--first, there must be some estimate of expected variability, and second, some idea of the cause of climate variability. There has been speculation that a warming planet has an unstable climate and that variability is a more important aspect of a changing climate than averages (Brown and Katz, 1991). This speculation has been borne out somewhat during recent reversals of global temperature trends. If the observed variability is related to observed global trends, some measure of crop response can be estimated.

The stress degree days is an elementary analytical method for relating temperature variability to crop response. Judging from the stress response to temperature trends, it may be inferred that variability will continue unabated as long as global warming continues. The cause of global temperature trends is important to estimation of the duration of instable production conditions. There has been considerable speculation that greenhouse gases contribute to an overall planetary warming. Temperature trend reversals during recent years may, however, be caused by changes in solar luminosity as related to the occurrence of sunspot activity (Friis-Christensen and Lassen, 1991). There is a strong correlation of the temperature trend with the sunspot activity cycle. Only recently, however, has there been direct measurement of a significant change in the radiant energy received from the sun associated with the activity (Willson et al., 1986).

Heating And Cooling Requirements

There are numerous expressions of climatic stability during the period of global cooling from 1940 to 1972. The examples likewise demonstrate heightened variability during the periods of global warming. Consistency of winter conditions may be expressed as heating degree days and summer conditions by growing degree days or by cooling degree days.

A number of public utilities use "cooling" and "heating degree day" climatology to anticipate seasonal energy demand. The heating degree day is a simple computation, involving temperature, used to anticipate energy demands for commercial and residential heating requirements. The calculation assumes that an average daily temperature of 65°F is associated with minimal power demands for environmental control of structures. Demands for cooling increase linearly as the average temperature warms above 65°F. Energy demands for heating increase as temperatures decrease in like manner.

Heating degree day computations were made using data from the most reliable long-term weather recording locations in Iowa. It was anticipated that a mid-continent location would not be strongly influenced by climate moderating influences of large bodies of water and may serve as an indicator of large-scale climatic trends and variability. Historical data for the state of Iowa were prepared by R. E. Carlson of Iowa State Univ., and heating degree day computations were produced for 34 sites. The average of all sites is seen in Figure 3. The inter-annual heating requirement exhibited considerably greater variability during the 1890-1939 period of global heating than is apparent from 1940-1975. The winter-to-winter heating requirements during the 1960s showed relatively little variability. The period has been termed one of benign weather by local residents. An increase in variability since 1975 is clearly discernable.

Computation of annual cooling degree days for the state of Iowa showed a similar pattern of reduced variability during the 1956-1979 period (Figure 4). There is some indication of a trend of increasing summer temperatures, as expressed in cooling degree days, from 1900 through 1936 and of decreasing temperatures from 1937 through 1974. The decreased variability and the cooling trend of the latter period are consistent with reported global temperatures.

Accumulated heat stress during the summer was not necessarily reduced during the interval of global cooling. However, the year-to-year variability of accumulated heat was clearly diminished. The observation implies that energy demand to control the environment of commercial and residential structures will be unstable so long as global warming continues. Likewise, residential and commercial energy demands during winter are not expected to be consistent so long as warming continues.

Sensitivity To El Niño

Pacific warming and resultant weather patterns and anomalies that are linked together under the general name "El Niño" are being extensively studied and modeled (Kerr, 1992). It is possible that the apparent increase in climate variability during global warming results in greater sensitivity of mid-continent locations to wide area weather anomalies such as the well-known El Niño event. Also, it is possible that the warming conditions increase the magnitude of the event itself. The relationship of the El Niño and corn (maize) yield in Iowa is immediately apparent when years of El Niño occurrence are marked on the record of corp yield (Figure 1). The occurrences of the El Niño data are given by Swetnam and Betancourt (1990). A close relationship of favorable crop yields to the El Niño event is seen. Additionally, it is clear that periods of sharply reduced yield (usually associated with drought) tend to occur during the season following an El Niño event. Analysis of data for the other Corn Belt states demonstrated like results.

During the interval of global cooling, especially from 1955-1972, the effects of the El Niño on crop yields do not appear to be significant (Figure 1). Also, during the cooling trend there was little indication of yield reduction during the year following the El Niño event.

Conclusions

The global temperature trends during the past 100 years have not been extreme when judged by the standards of anticipated "greenhouse" warming nor in comparison to inferred temperature extremes during the geologic past. However, the apparent expression of global temperature trend in the form of inter-annual climate variability is sufficient to imply that variability may be a principal expression of climate change.

Variability of over-winter harshness may be expressed in terms of potential heating requirements--"heating degree days." Summer variability is discernable in the form of potential requirements for cooling "cooling degree days" and as stress upon the development of crops--"stress degree units." The ultimate indicator of climate variability may be the actual crop yields, which may be considered to be the integration of all factors over a season. The year-to-year yield variability diminished from 1940 through 1955 and then remained minimal through 1972 when the trend of global warming was established, or perhaps resumed.

The El Niño event has been shown to be correlated with measurable weather trends in numerous global locations. The influence on crop yields in the midwest is substantial. However, influence of the event appeared to be minimal during the period of global cooling and substantial when the trend of global temperature was increasing.

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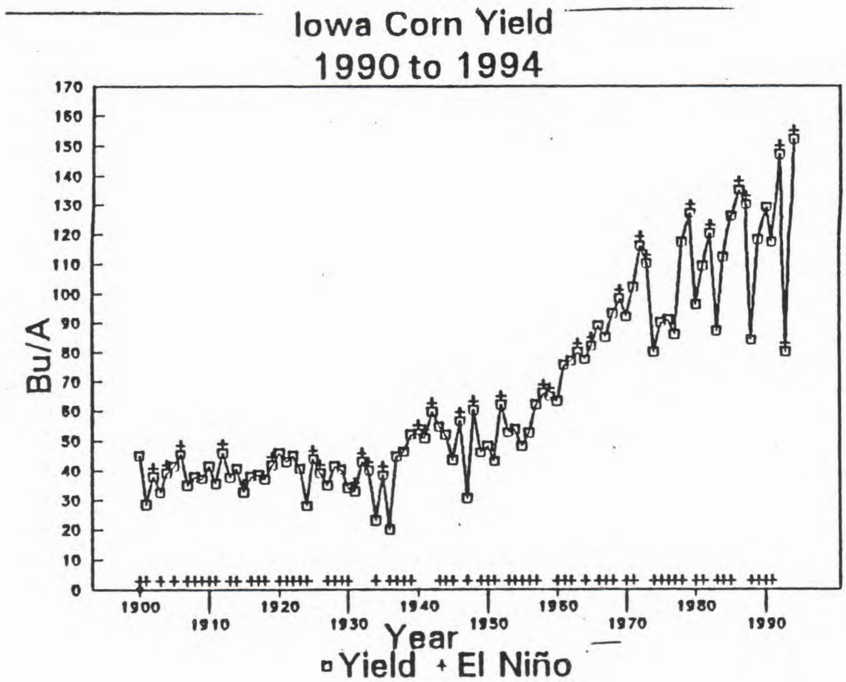

Figure 1. Iowa corn yield 1900-1992. Data from USDA (1951, Fluctuation in crops and weather 1866-1948, USDA Statistical Bulletin #101, also USDA Ag. Statistics for yields since 1949). El Niño events are indicated by +.

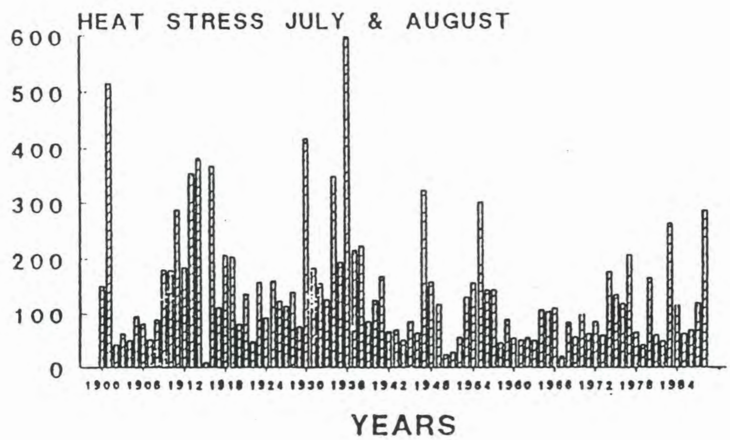

Figure 2. Crop heat stress. Mid-season heat stress if often associated with reduced grain yields in Iowa. The severity of crop heat stress was diminished during the latter portion of the 1940-1972 period of global cooling. (Data provided by R. E. Carlson, Iowa State Univ.)

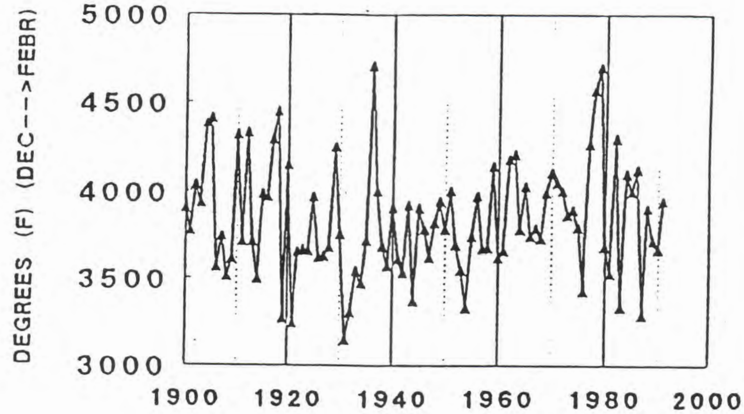

Figure 3. Heating degree days. The amount of energy required to heat commercial and residential structures is estimated from seasonal temperature using the heating degree day. The year-to-year variability of the heating degree day accumulation was greatly diminished during the 1940-1972 period of global cooling. (Data provided by R. E. Carlson, Iowa State Univ.)

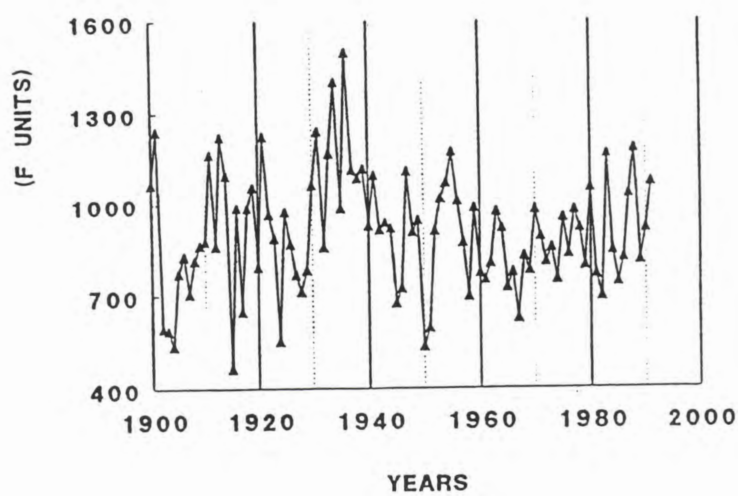

Figure 4. Cooling degree days. Energy requirements to cool commercial and residential structures is estimated from seasonal temperature using the cooling degree day. The year-to-year variability of the cooling degree day accumulation was diminished during the 1940-1972 period of global cooling. (Data provided by R. E. Carlson, Iowa State Univ.)